



# 32 GT/s Waveform Post Processing and Statistical Simulation

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# Disclaimer



**Presentation Disclaimer: All opinions, judgments, recommendations, etc. that are presented herein are the opinions of the presenter of the material and do not necessarily reflect the opinions of the PCI-SIG®.**

# Acknowledgments



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- **Explore the consistency between a waveform post-processing tool and a statistical simulation tool for possible use at 32 GT/s**
- **Establish a methodology for accurately comparing a waveform post-processing tool and a statistical simulation tool by creating an equivalent environment**
- **Attempt to understand differences between the tools for use at 32 GT/s**

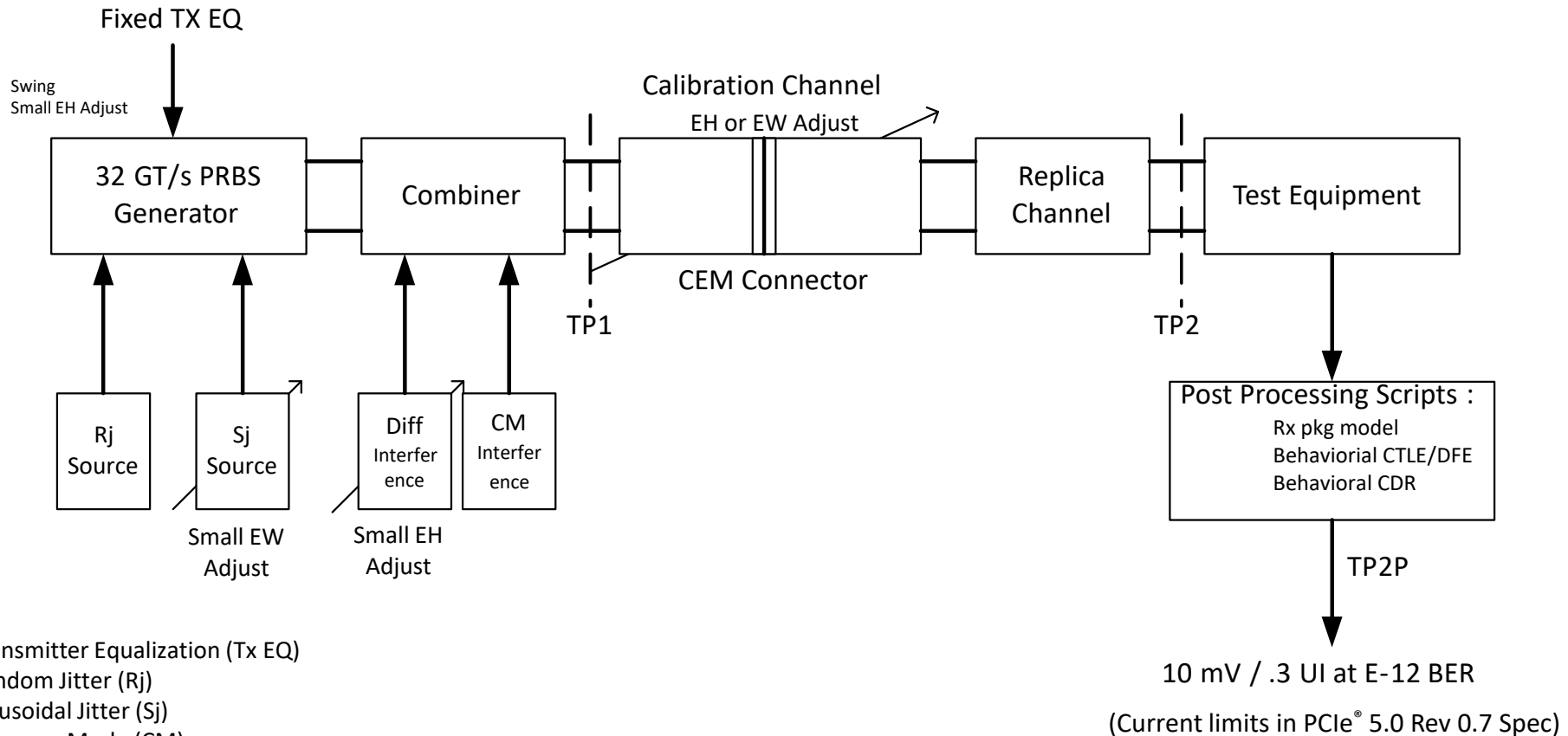
# Agenda



- **32 GT/s Proposed Rx Calibration Methodology**
- **Overview of Tools for Comparison**
- **Lab Setup and Methodology**
- **Guidelines for Equivalency**
- **Results Summary**
- **Next Steps**

# **32 GT/s Proposed Rx Calibration Methodology**

# Calibrating Stressed Eye



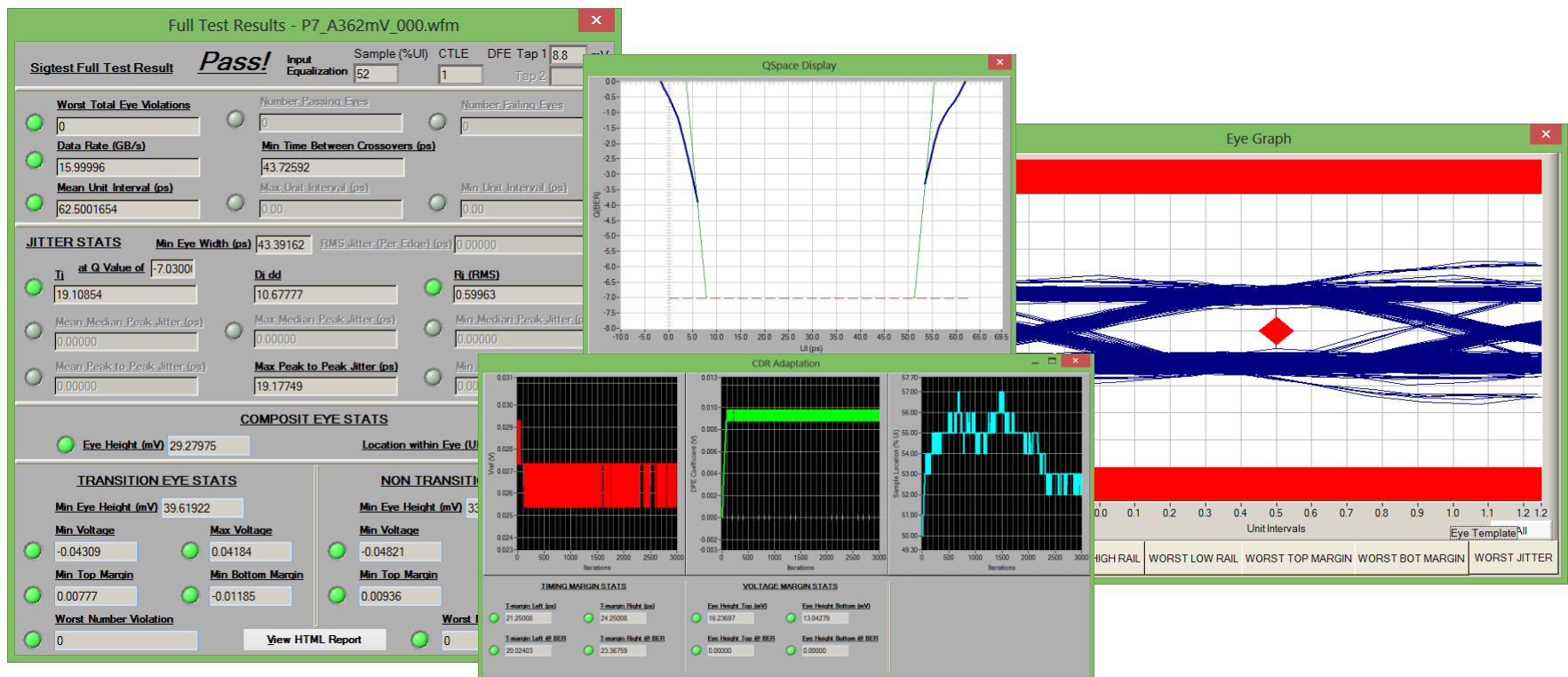
# Overview of Tools for Comparison



# Waveform Post Processing Tool (SigTest)



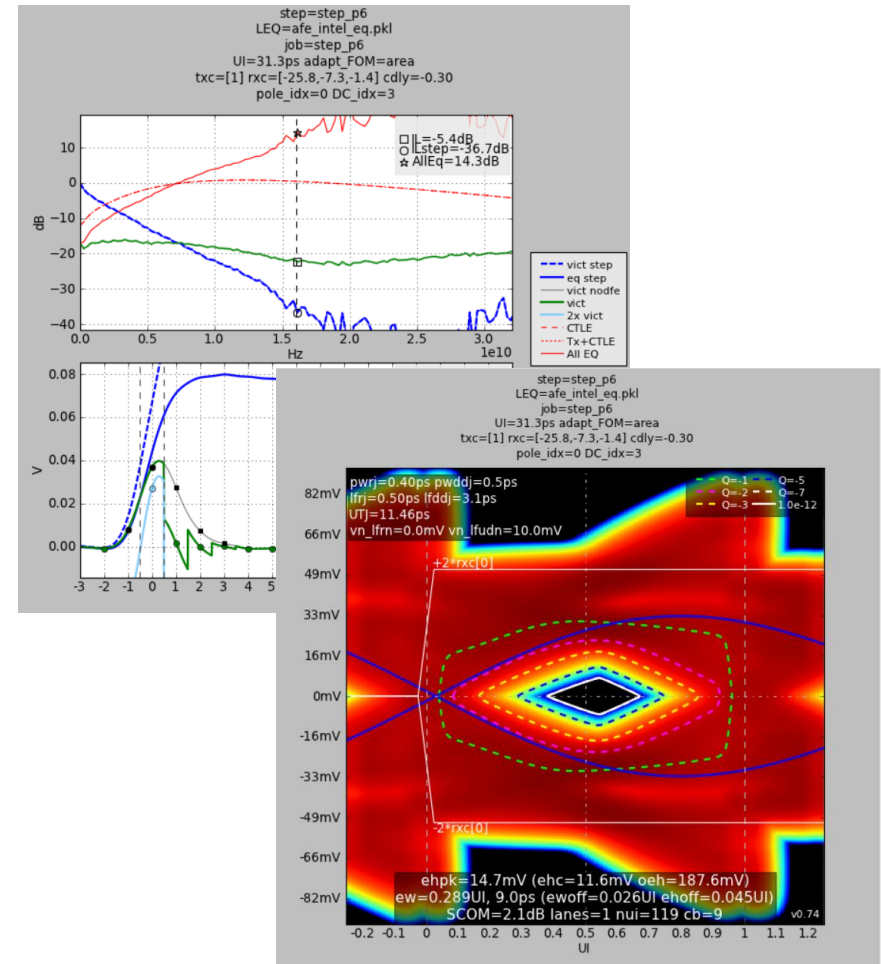
- **SigTest is a high-speed IO waveform analysis tool used for post-silicon verification and compliance**
- **SigTest performs closed loop (jitter & noise included) end of channel eye diagram measurements for PCIe Rx Calibration**



- **Time Domain CDR**
  - Peak Detect
  - Mueller-Muller (Zero First Pre-Cursor)
- **DFE Adaptation**
  - DFE adaptation is performed in CDR loop
  - Sign-Sign LMS algorithm
  - Error term based on  $V_{ref}$  (also adaptive)
- **Improved DFE Application**
  - DFE Voltage shifts based on CDR recovered clock
  - Closed eye post CTLE waveforms can be opened with new DFE implementation

# Statistical Simulation Tool (Seasim)

- **Statistical data eye simulator to evaluate channel compliance**
- **Written in Python**
- **Accepts Step Response for victim & aggressor channels**
- **Stress (Jitter & noise) added**
- **Tx and Rx equalization is comprehended**
- **Margin is reported at a specified BER**

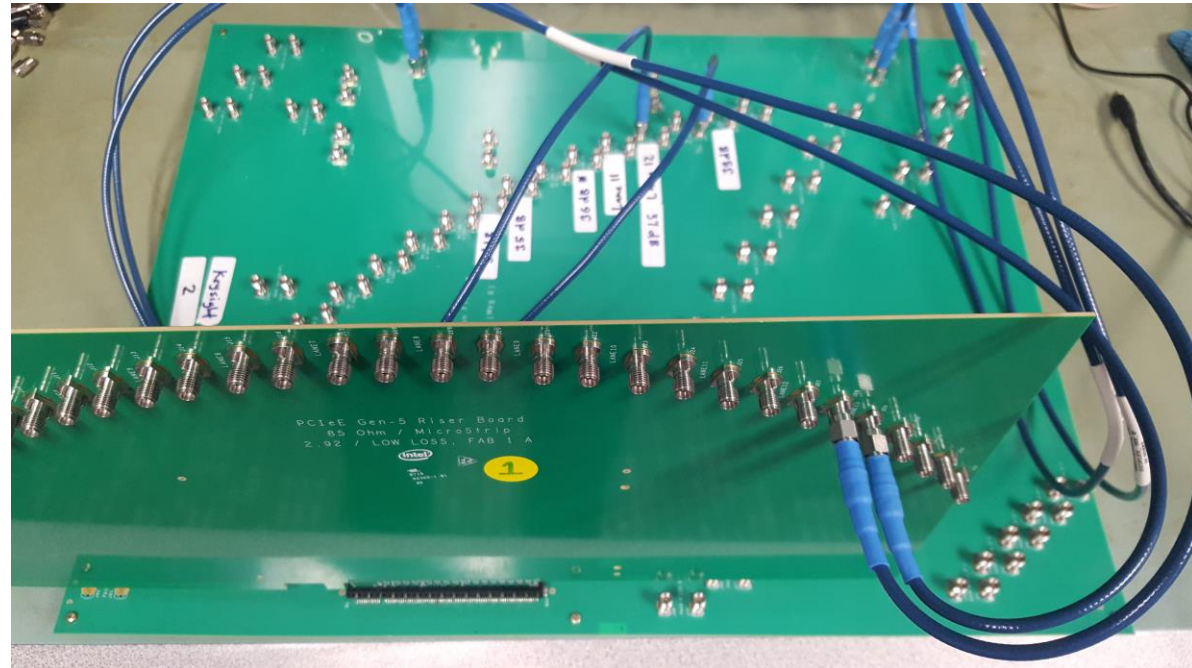


# Lab Setup and Methodology

## ○ **Compare SigTest with Seasim**

- Comparison is done with 36 & 38 dB channels containing a real CEM connector and different levels of stress (low stress, nominal stress, & high stress)
- SigTest 4.0.29 (including Base Spec Rev 0.7 CTLE)
- Seasim 0.74
- Eye Width & Eye Height Compared @ BER E-6

- **PCIe 5.0 Base Rx Calibration Prototypes – 2.92mm coaxial with Meg6 (low loss)**
  - Prototype fixture were available for sale to the Electrical Working Group members
  - Explored 36 & 38 dB channels with integrated Meg6 replica channel
  - Amphenol FCI CEM connector
    - layout optimization (sentry vias, merged gnd vias, side-band signal terminations)
  - Microstrip differential traces – fan-out with large diameter curves
  - 85 Ohm impedance
- **Signal Generators**
  - Anritsu MP1900
  - Keysight M8045A
  - Tektronix BSX320
- **Real Time Scopes**
  - Keysight DSAZ634A
  - LeCroy LabMaster 10-36ZI
  - Tektronix DPO70000SX
- **Coaxial Cables**
  - Huber Suhner
    - SUCOFLEX\_102\_E



# Constructing Stressed Signals



- **Waveform & Step Capture**
  - Waveforms (2.0 Million UI) are captured for SigTest
  - Step responses (Averaging of 1024) are captured for Seasim
- **Tx Equalization**
  - Tx EQ is injected from the Signal Generator for both the waveform and step response captures
- **Sinusoidal Jitter (Sj) @ 100 MHz**
  - Signal Generator injects Sj into the waveform
  - Sj is not comprehended in step response (added in simulation)
- **Random Jitter (Rj)**
  - Signal Generator injects Rj into the waveform
  - Rj is not comprehended in step response (added in simulation)
- **Differential Mode Interference (DMI) @ 2.1 GHz**
  - Signal Generator injects DMI into the waveform
  - DMI is not comprehended in step response (added in simulation)

# Signal Generator Settings



- **Swing – 800 mV Peak-to-Peak**
- **Tx Equalization – P0 to P9**
  - Preset with optimal eye used for comparison
  - Waveform approach may prefer a different preset than simulation
- **Pattern**
  - Simulation – 256 ones / 256 zeros (step response)
  - Waveform – PCIe 4.0 Compliance pattern (64 ones / 64 zeros removed)
- **Low Stress**
  - $R_j$  – 0.5 ps RMS
  - $S_j$  – 0.05 UI
  - DMI – 5 mV
- **Nominal Stress**
  - $R_j$  – 0.5 ps RMS
  - $S_j$  – 0.1 UI
  - DMI – 10 mV
- **High Stress**
  - $R_j$  – 0.5 ps RMS
  - $S_j$  – 0.15 UI
  - DMI – 15 mV



# Channel Step Response Capture Details



- **Signal Generator used to transmit**
  - 800 mV Peak-to-Peak Amplitude
  - 256 Ones 256 Zeroes Pattern
  - Tx EQ: P0 – P9 (enabled in BERT, but disabled in Seasim)
  - No Jitter or Noise
- **Real-Time Scope Capture**
  - End of Calibration Channel
  - Scope Bandwidth: 33 GHz
  - 1024 Steps are Averaged
  - Horizontal Scale: 400ps / division
  - Vertical Scale: Maximize the step response on the screen
  - Trigger: Capture rising edge at third tick of the first division

# Channel Step Response Example



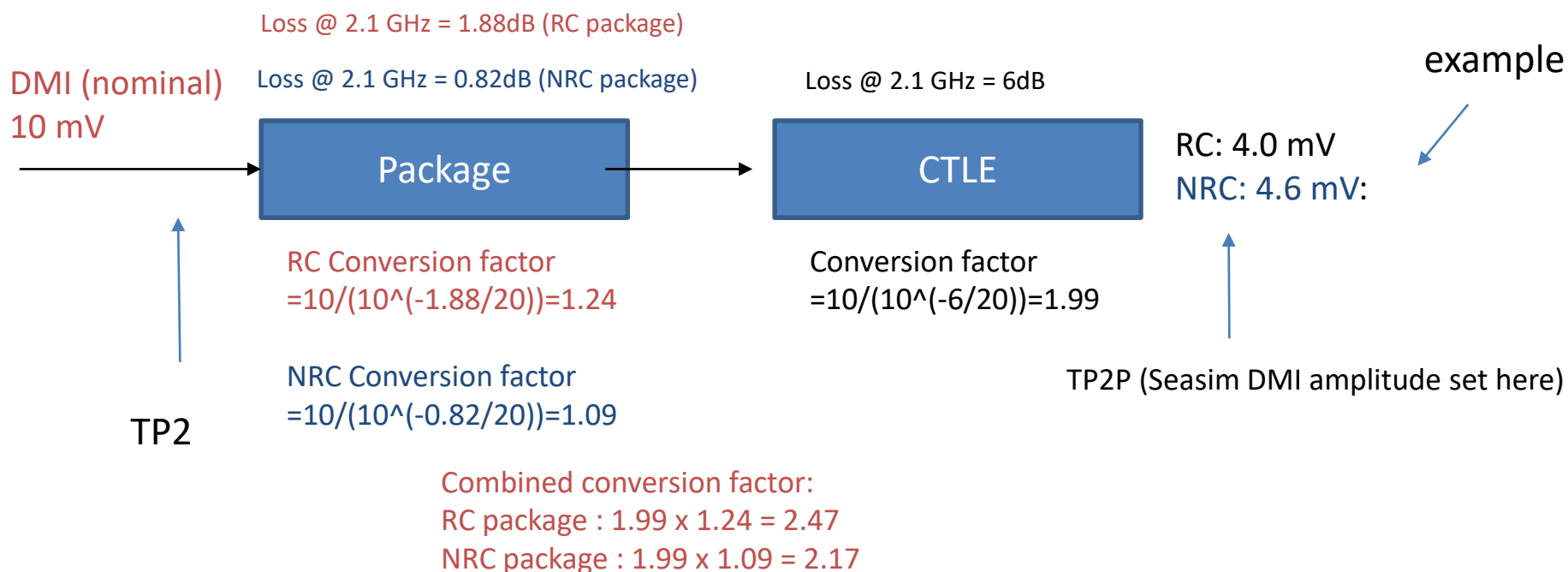
# Guidelines for Equivalency

# DMI CTLE & Package Interaction



- **Differential Mode Interference (DMI)**
  - DMI is not comprehended in Step Response
  - Waveform method includes DMI before embedding (TP2) the package model and applying the behavior CTLE so an interaction (attenuation) occurs
  - Simulation method adds DMI post package embedding and CTLE so no interaction occurs
  - The DMI amplitude must be adjusted (less in simulation) for an equivalent comparison between the waveform method and simulation

# Simulation DMI Conversion Factor

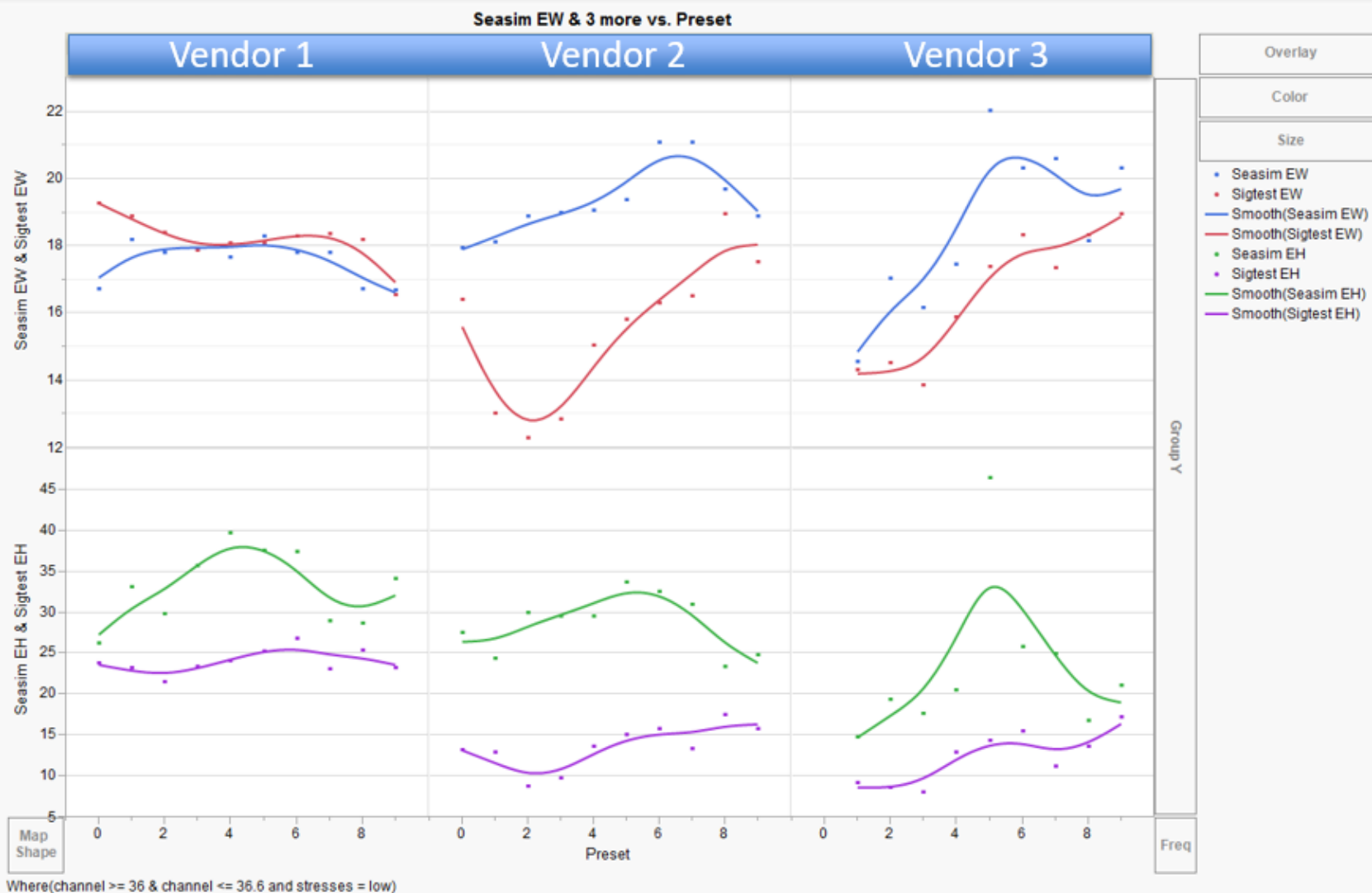


(Nominal DMI value based on PCIe 5.0 Rev 0.7 spec)

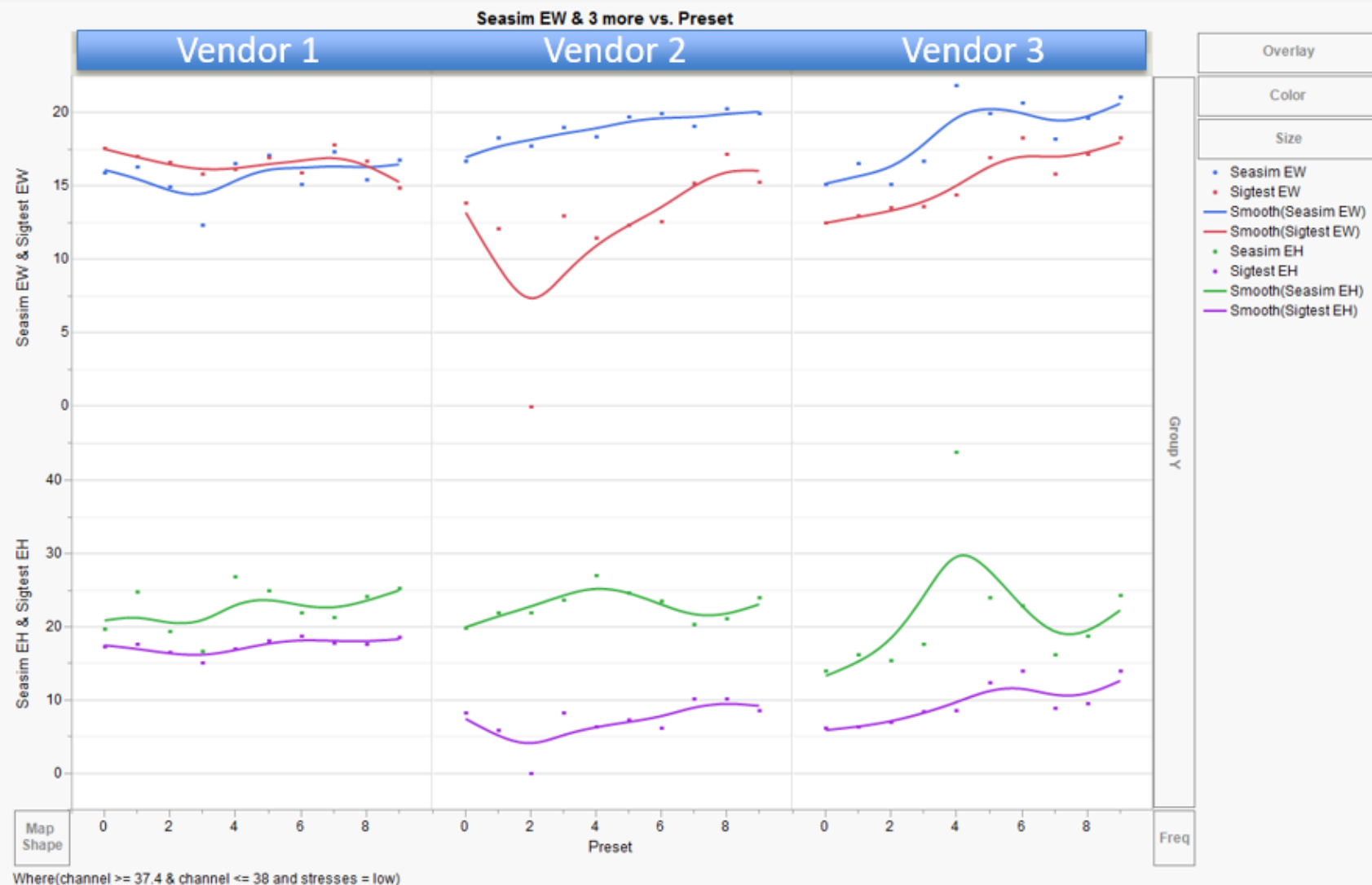
Root Complex (RC)  
Non-Root Complex (NRC)

# Results Summary

# Correlation Results: 36dB Channel with Low Stress

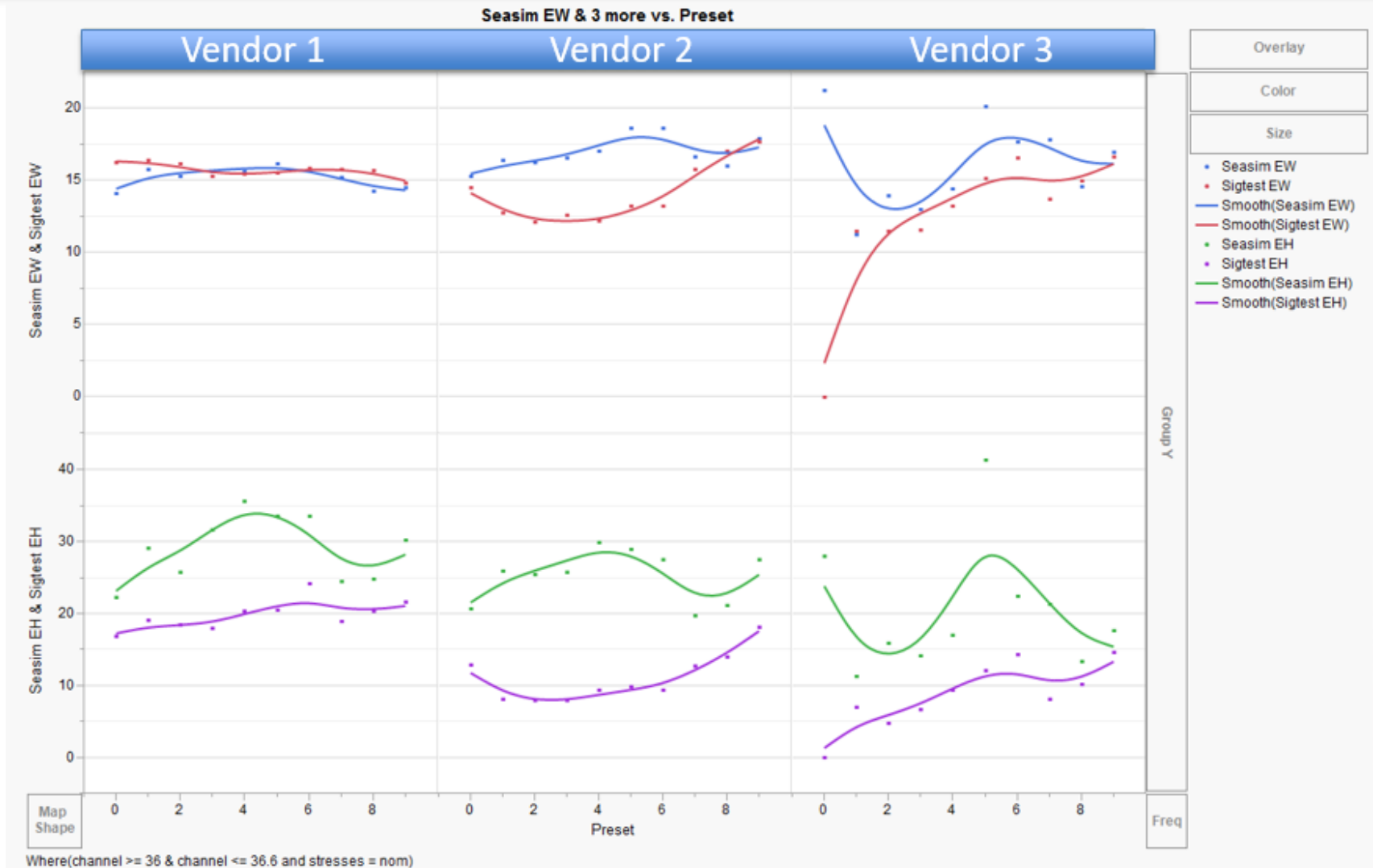


# Correlation Results: 38dB Channel with Low Stress

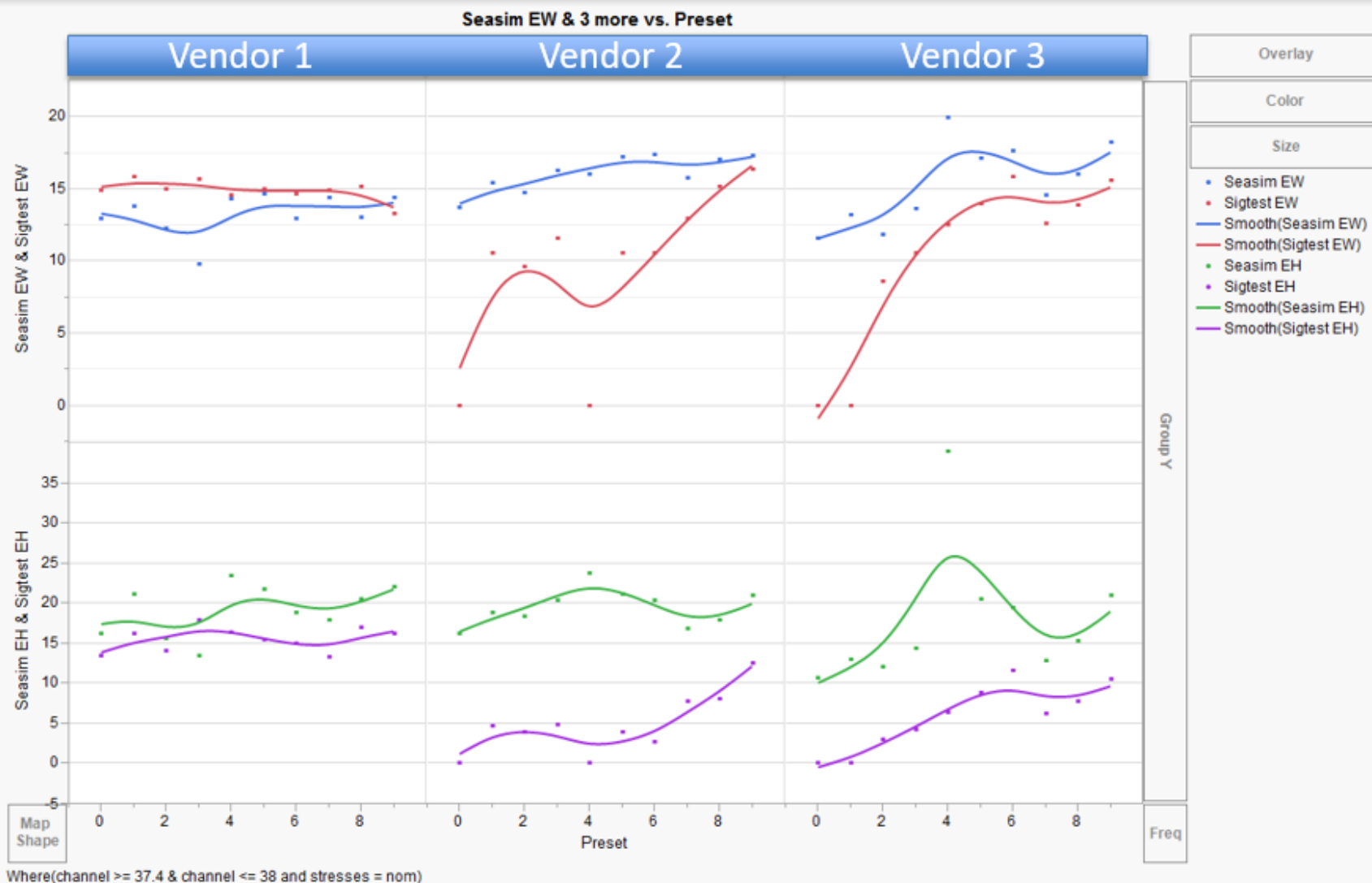




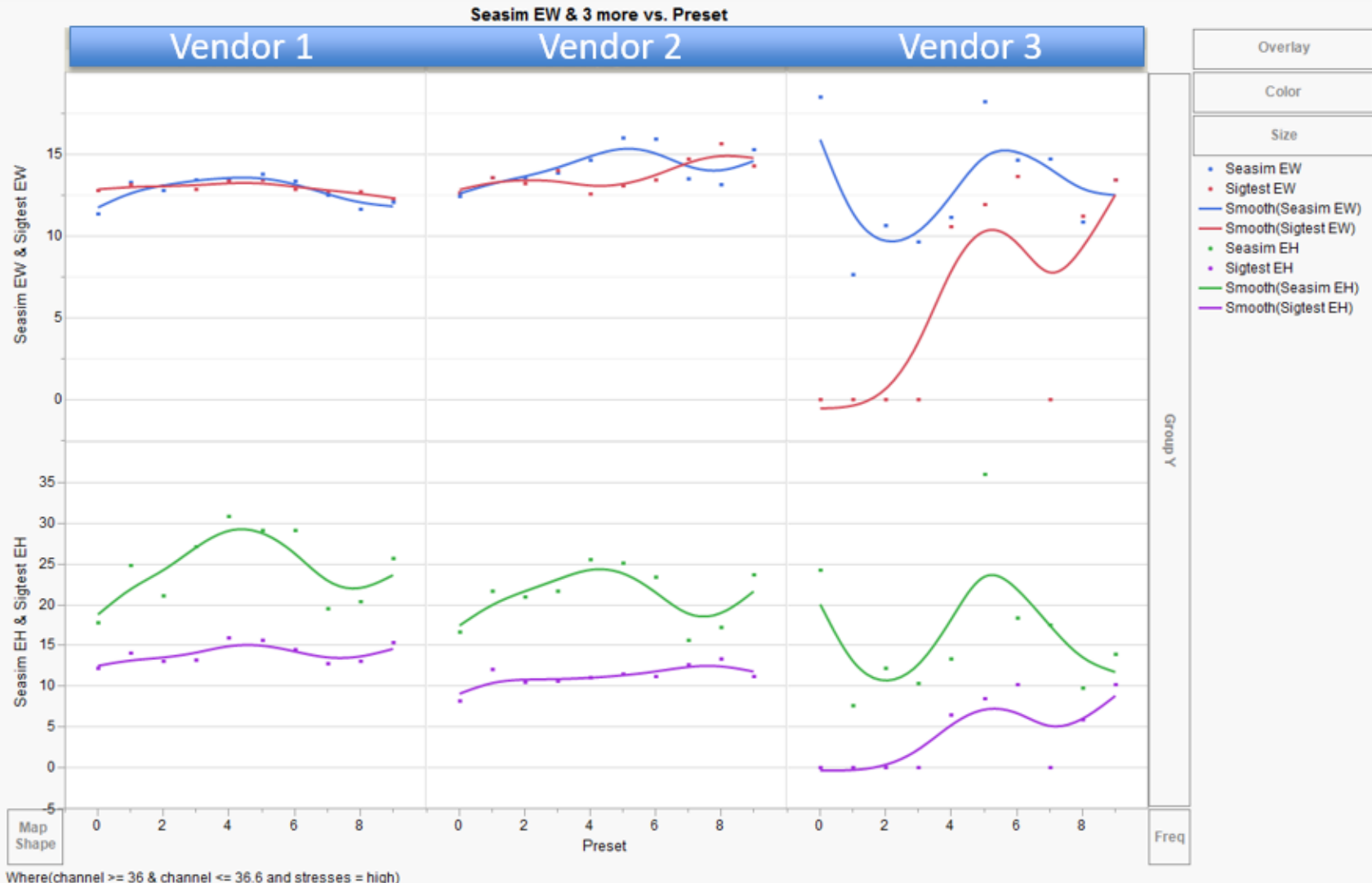
# Correlation Results: 36dB Channel with Nominal Stress



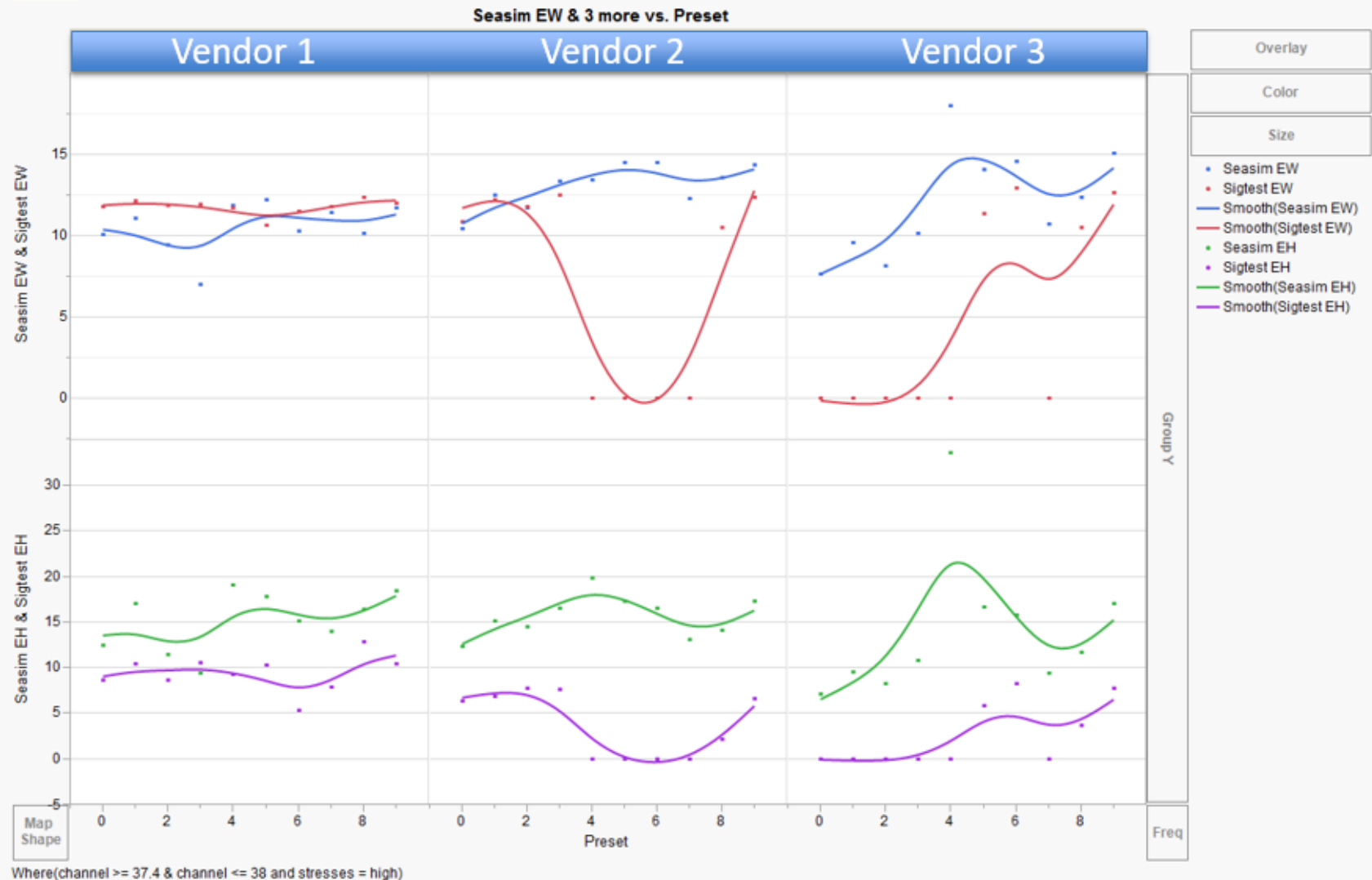
# Correlation Results: 38dB Channel with Nominal Stress



# Correlation Results: 36dB Channel with High Stress



# Correlation Results: 38dB Channel with High Stress



# Summary of Correlation



## ○ **Eye Width Correlation Observations**

- Reasonable EW correlation is achieved with the optimal Tx EQ Preset between SigTest and Seasim for both channels and all stress combinations
- EW correlation between SigTest and Seasim varies across test equipment vendors
- The optimal Tx EQ Preset is different across test equipment vendors & between SigTest & Seasim

## ○ **Eye Height Correlation Observations**

- Seasim is consistently reporting a larger EH with the optimal Tx EQ Preset for both channels and all stress combinations
- Signal Generator and Scope noise may be the cause of this miscorrelation

- **The waveform post-processing tool and the statistical simulation tool are consistent for eye width but show a miscorrelation for eye height**
- **A methodology for accurately comparing a waveform post-processing tool and the statistical simulation tool needs additional attention**

# Next Steps

# Presenter's Next Steps



- **Impact of generator and scope noise needs to be explored for the waveform approach**
- **Need to explore correlation with eye width/height extrapolation**
- **Introduce the Rx Package embedding**
- **Investigate the feasibility of using channel length, Swing, S<sub>j</sub>, & DMI as knobs for calibrating the stressed eye to specific targets**
- **Continue to explore consistency across different test equipment**



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